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CARBOHYDRATE TRANSFORMATIONS IN SWEET POTATOES

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INTRODUCTION

In a former paper[1] embodying a study of the general course of the carbohydrate transformations in sweet potatoes (*Ipomoea batatas*) during storage, certain data were presented indicating that the sugar content of sweet potatoes remains comparatively low while they are in the ground, but that immediately after the roots are harvested there is a transformation of starch into sugar which takes place more rapidly at that time than at subsequent periods. It was pointed out that this initial transformation seemed to be not greatly affected by temperature, but seemed rather to depend upon internal factors. It was suggested that possibly this initial change was associated with the cessation of the activity of the leaves. In view of the fact that this initial change appeared to be a phase of the carbohydrate metabolism of the sweet potato which was inaugurated only under certain conditions and which differed in some respects from subsequent changes, it seemed worth while to investigate this process more fully in order to make out something, if possible, as to its nature by a study of its progress at different temperatures.

EXPERIMENTATION IN CARBOHYDRATE TRANSFORMATION

PLAN OF EXPERIMENTS

The plan carried out in this work was, in general, to compare the carbohydrate transformations taking place in sweet potatoes during a period of 10 or 12 days immediately after they had been dug with the changes taking place during a second subsequent period of equal length. These experiments were carried out at temperatures of 30°, 15.5°, and 5° C.

[1] Hasselbring, Heinrich, and Hawkins, L. A. Physiological changes in sweet potatoes during storage. *In* Jour. Agr. Research, v. 3, no. 4, p. 331–342. 1915. Literature cited, p. 341–342.

The sweet potatoes used in the first series of experiments were dug on September 30, thoroughly washed, and were kept covered in the laboratory until the following day. In the further manipulation each potato was split lengthwise into two parts as nearly equal as possible. So far as could be determined the potatoes were cut longitudinally in a dorsiventral plane. One half, marked "a," was ground immediately, and samples were taken from the mash for the determination of moisture, sugar, and starch. The other half, marked "b," was stored. Six halves were stored at each temperature, the corresponding halves having been grated and sampled as described. The operation of preparing and sampling the halves for a set of experiments at the three temperatures required two days. Simultaneously with the halves a number of whole sweet potatoes were put into the constant-temperature chambers in which the experiments were conducted. At the end of 12 days the stored halves were taken out, grated, and sampled. After the completion of this operation, which required two days, the stored whole potatoes (which during this time had been subjected to the same conditions as the stored halves) were split lengthwise, like the first set, and one half was prepared for analysis. The other half was stored for another period of 12 days, after which it also was grated and analyzed. It will thus be noted that the difference in composition of the two halves of the first set of roots showed the change during the first period of 12 days immediately after the potatoes had been dug, while the difference in composition of the two halves of the second lot showed the change for a second period of 12 days immediately following the first period.

Although the time during which the sweet potatoes were exposed to the experimental conditions was essentially the same for the comparable lots, some unimportant differences necessarily crept in. Thus, for instance, it was impossible to prepare a complete set in a single day; therefore, one half of the potatoes used in the experiment were prepared one day and the other half the following day. Consequently, the one lot remained in the laboratory about a day longer than the other. Also, although the different groups were taken out of their respective chambers in the same order in which they were put in, no attention was paid to the order in which the individual potatoes were removed, since it was necessary to work as rapidly as possible. On this account it is likely that some halves remained in the chambers a few hours longer and others a few hours less than the assigned period, but it is obvious, considering the slowness of the changes that take place, that these discrepancies can have no effect on the general result.

The whole sweet potatoes stored simultaneously with the first set of halves also remained in the chambers two days longer than the halves, on account of the time required to grind and sample the stored halves; but this also is of no consequence, since the object of the experiments was

to compare the changes in the roots during the period immediately after they were dug with those during a subsequent period of the same length.

The second series of experiments was in all respects like the first except that the potatoes were dug on October 16 and placed in the experimental chambers on October 17 and 18. The length of time of storage was 12 days.

It was the object of the third series of experiments to determine the effect of removal of the vines on the initial carbohydrate changes in the sweet potato. The potatoes used in this series were, therefore, not dug until some time after the vines had been killed. The first frost, which killed the leaves but not the vines, occurred on October 22; a few days later, October 27, the vines were cut off close to the ground, so that from this time there would be no further transfer of materials from the vines to the roots. The potatoes were dug on November 6 and were thereafter treated as described for the other experiments, with the exception that the storage period was 10 days.

METHODS OF ANALYSIS

The methods of analysis were essentially the same as formerly described.[1] Only a few exceptions need be noted. The samples for moisture determinations were covered with 95 per cent alcohol as before, but the alcohol was evaporated in a drying oven at 50° C. Thereupon the samples were dried to their lowest weight in a vacuum oven in a slow current of air. This procedure gave clean, nearly white samples. For the starch determinations 10 gm. were weighed out and the whole sample, instead of an aliquot, was extracted, ground, and used for hydrolysis. The sugar samples were put into flasks, which were then nearly filled with 70 per cent alcohol, with the addition of a little calcium carbonate, and boiled for a minute or two. The starch samples were stored, without boiling, in 95 per cent alcohol.

GENERAL OBSERVATIONS ON THE EXPERIMENTS

In the experiments described halves of the same sweet potato were compared with each other, the one being analyzed immediately and the other at the end of a 10 to 12 day period of storage. Two questions immediately arise regarding this procedure, which was adopted because different sweet potatoes of the same variety differ much in composition: First, are the halves of the same potato alike in composition; and, second, do the cut potatoes behave in the same manner as whole potatoes in storage?

Müller-Thurgau[2] in his work on the common Irish potato found that there were only slight differences in the sugar content of the two halves

[1] Hasselbring, Heinrich, and Hawkins, L. A. Physiological changes in sweet potatoes during storage. *In* Jour. Agr. Research, v. 3, no. 4, p. 331–342. 1915. Literature cited, p. 341–342.

[2] Müller, Hermann, *Thurgau*. Ueber Zuckeranhäufung in Pflanzentheilen in Folge niederer Temperatur. Ein Beitrag zur Kenntniss des Stoffwechsels der Pflanzen. *In* Landw. Jahrb., Bd. 11, p. 751–828, pl. 26. 1882.

of potatoes cut lengthwise; it was therefore somewhat astonishing to find considerable differences in the two halves of sweet potatoes which were examined in July and August and which had been stored up to that time from the previous year. On this account further examinations were made of freshly dug sweet potatoes and of others of the same crop which had been stored in the chambers with the experimental sweet potatoes. The results of these examinations are given here.

On September 9 three freshly dug sweet potatoes were split dorsiventrally as nearly as could be judged. While one half was being prepared for analysis the other was kept wrapped in a damp cloth. From the mash of each grated half two samples were weighed out for sugar determinations, two for starch, and two for moisture. From each of the sugar samples and from each of the starch samples two determinations were made. The results calculated in percentages are given in Table I. The halves of the same potatoes are indicated by "a" and "b." The data afford an opportunity to estimate the error that is likely to occur in duplicate determinations in one sample, the error in sampling, and also the difference in composition of the halves of the same potato. The data show that the longitudinal halves of freshly dug sweet potatoes have very nearly the same composition and that errors due to method and technique are negligible.

TABLE I.—*Percentage composition of halves of freshly dug sweet potatoes*

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Cane sugar.	Starch.
1a	71.75	0.66	2.27	21.00
		.66	2.23	20.99
1a	71.80	.68	2.20	21.00
		.68	2.25	20.95
1b	71.23	.79	2.17	21.42
		.78	2.21	21.47
1b	71.29	.75	2.21	21.43
		.77	2.25	21.53
2a	73.53	.87	2.01	19.58
		.85	2.00	19.47
2a	73.55	.90	1.95	19.69
		.90	1.93	19.55
2b	74.47	.94	1.95	18.32
		.95	2.03	18.44
2b	74.32	.98	2.00	18.28
		.96	2.01	18.16
3a	73.04	1.13	1.74	19.59
		1.15	1.68	19.78
3a	73.08	1.16	1.68	19.60
		1.16	1.60	19.58
3b	73.29	.....	.....	19.33
		.....	.....	19.39
3b	73.14	1.29	1.71	19.21
		1.32	1.66	19.25

To determine the effect of storage on the composition of different parts of the same sweet potato a number of other potatoes which had been stored for various lengths of time under different conditions were examined. One set of three potatoes was kept in the laboratory for four days. The other sets were stored for a month in the different chambers with the experimental potatoes.

In this case two samples were taken from each half, but the determinations were not made in duplicate for each sample. The results of these analyses are collected in Table II.

TABLE II.—*Percentage composition of halves of sweet potatoes kept for various times under different conditions*

KEPT IN LABORATORY FROM NOV. 6 TO NOV. 10

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Percentage of difference between halves.	Cane sugar.	Percentage of difference between halves.	Starch.	Percentage of difference between halves.
148a	74.64	1.21	9.9	3.01	2.6	16.36	1.4
	74.58	1.21		3.06		16.33	
148b	74.46	1.09		2.97		16.53	
	74.52	1.09		2.94		16.61	
149a	76.48	1.41	4.3	3.51	2.4	13.93	8.4
	76.48	1.40		3.52		14.09	
149b	75.49	1.36		3.43		15.22	
	75.48	1.33		3.43		15.16	
150a	76.32	.82	16.4	3.40	.3	14.45	3.4
	76.28	.83		3.36		14.68	
150b	76.72	.96		3.38		14.20	
	76.69	.96		3.40		13.93	

STORED IN 30° C. CHAMBER FROM NOV. 7 TO DEC. 5

110a	73.47	0.74	14.1	4.72	6.3	15.49	3.9
	73.44	.75		4.69		15.54	
110b	72.62	.64		4.97		16.21	
	72.52	.64		5.03		16.04	
111a	72.29	.70	6.3	4.82	2.2	16.79	3.1
	72.27	.72		4.78		16.57	
111b	72.06	.76		4.93		17.27	
	72.01	.75		4.88		17.14	

STORED IN 15.5° C. CHAMBER FROM OCT. 17 TO NOV. 11

68a	71.83	1.18	1.7	3.71	7.0	18.22	2.3
	71.84	1.16		3.73		18.21	
68b	70.99	1.16		3.98		18.71	
	70.98	1.14		3.98		18.54	
69a	71.96	1.54	4.2	3.79	1.3	17.80	6.7
	71.92	1.54		3.79		17.82	
69b	73.52	1.47		3.73		16.64	
	73.49	1.48		3.75		16.61	

TABLE II.—*Percentage composition of halves of sweet potatoes kept for various times under different conditions*—Continued

STORED IN 5° C. CHAMBER FROM OCT. 17 TO NOV. 11

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Percentage of difference between halves.	Cane sugar.	Percentage of difference between halves.	Starch.	Percentage of difference between halves.
89a	76.30	2.35	5.5	4.35	2.5	12.02	3.9
	76.32	2.35		4.38		12.02	
89b	75.79	2.22		4.48		12.38	
	75.71	2.22		4.47		12.60	
95a	75.98	2.61	2.5	3.97	7.2	12.44	.4
	75.97	2.61		3.95		12.40	
95b	76.16	2.57		3.68		12.48	
	76.21	2.52		3.67		12.45	

The results indicate that the longitudinal halves of sweet potatoes which have been stored for a time are likely to show a greater dissimilarity in composition than the halves of freshly dug potatoes. The differences, however, are not sufficiently great to overshadow the significant differences seen in the later tables. The inequality in composition of the halves of the same potato is much less than the unlikeness of different potatoes. The method of comparison of halves is therefore more satisfactory than the comparison of different whole potatoes unless a sufficient number be used to obliterate, to a great extent at least, errors due to individual differences.

The question whether the cut halves behave in the same way in storage as whole sweet potatoes can be more easily discussed in connection with the data presented later. It should be mentioned here, however, that in the first experiment at 15.5° C. the halves lost an unusual quantity of moisture and that this drying may have had some influence on their behavior. In subsequent experiments precautions were taken to avoid a loss of moisture as far as possible.

EXPERIMENTAL DATA

The data relating to all the experiments are collected in Tables III, IV, and V. Table III contains the data of the three experiments conducted at 30°, Table IV those of the experiments at 5°, and Table V those of the experiments at 15.5° C. Under each experiment the first section refers to the changes in composition of the sweet potatoes during the first period of 10 to 12 days immediately after the roots were dug, while the second section gives the changes during a period of equal length immediately following. The change during each period is shown by the difference in composition between the "a" halves analyzed at the beginning of their respective periods and the "b" halves of the same potatoes analyzed at the ends of the periods. The data in each case are based on the water content of the first half of the potato analyzed. The columns of differences show, respectively, the difference in the percentage of

reducing sugar, cane sugar, and starch in the half of the potato analyzed at the beginning, and the corresponding half analyzed at the end of the same period. These differences therefore represent the increments in the percentage of these substances in the stored halves during the 10- or 12-day storage period.

In the discussion of these tables it will be most convenient to compare the results of the experiments conducted at 30° with those of the experiments conducted at 5° and to consider later the experiments at 15.5° C.

The first and second experiments carried out at 30° (Table III) are similar in plan and execution and the results are entirely congruous, so that they may be discussed together. In both of these experiments there is a marked loss of starch during the first period of 12 days following the digging of the potatoes, but very little further loss during the second period. The changes in cane sugar correspond inversely to the changes in starch. During the first period there is a large increase in cane sugar, but during the second period there is almost no further gain. The figures showing the changes in reducing sugar during the first period are irregular, but during the second period there is a consistent and well-marked loss.

TABLE III.—*Changes in composition of sweet potatoes at 30° C.*

FIRST EXPERIMENT (FIRST PERIOD)

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Difference.	Cane sugar.	Difference.	Starch.	Difference.
	Per cent.	*Per cent.*		*Per cent.*		*Per cent.*	
4a	74.02	0.47	0.37	2.63	1.95	18.91	−3.32
4b	68.63	.84		4.58		15.59	
5a	73.11	.79	.23	2.38	1.68	19.44	−2.42
5b	70.41	1.02		4.06		17.02	
6a	73.73	.91	−.26	2.09	2.43	19.16	−3.05
6b	66.38	.65		4.52		16.11	
7a	73.91	.80	−.06	2.22	2.63	18.88	−3.26
7b	65.71	.74		4.85		15.62	
8a	73.12	.81	.12	2.52	1.30	19.36	−1.93
8b	69.70	.93		3.82		17.43	
9a	74.06	.93	−.32	1.81	2.74	18.66	−3.06
9b	65.26	.61		4.55		15.60	

FIRST EXPERIMENT (SECOND PERIOD)

13a	71.10	1.41	−0.89	3.62	0.53	18.84	+0.13
13b	64.10	.52		4.15		18.97	
14a	72.52	1.23	−.74	3.61	.87	17.93	−.37
14b	66.50	.49		4.48		17.56	
15a	71.58	1.21	−.81	3.86	.79	18.23	−.09
15b	65.01	.40		4.65		18.14	
20a	74.15	1.38	−.72	3.79	.74	15.63	+.33
20b	66.14	.66		4.53		15.96	
21a	72.57	1.24	−.81	4.00	.88	17.49	−.52
21b	63.55	.43		4.88		16.97	
23a	73.25	1.44	−.86	3.36	.08	17.05	.75
23b	66.78	.58		3.44		17.80	

TABLE III.—*Changes in composition of sweet potatoes at 30° C.*—Continued

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Difference.	Cane sugar.	Difference.	Starch.	Difference.
	Per cent.	*Per cent.*		*Per cent.*		*Per cent.*	
SECOND EXPERIMENT (FIRST PERIOD)							
61a	76.39	0.35	0.12	1.71	1.76	16.09	−1.91
61b	72.21	.47		3.47		14.18	
62a	73.35	.89	−.01	1.93	1.90	19.35	−1.89
62b	71.63	.88		3.83		17.46	
63a	73.12	.71	.12	2.26	1.94	19.42	−2.22
63b	68.86	.83		4.20		17.20	
79a	72.48	.73	−.06	2.43	2.81	20.19	−3.20
79b	69.48	.67		5.24		16.99	
80a	73.88	.78	−.25	2.64	1.54	18.60	−1.41
80b	66.98	.53		4.18		17.19	
81a	74.20	.69	−.14	2.42	2.18	18.15	−2.49
81b	66.21	.55		4.60		15.66	
SECOND EXPERIMENT (SECOND PERIOD)							
75a	70.74	0.94	−0.31	3.73	0.75	20.11	−0.76
75b	70.43	.63		4.48		19.35	
76a	73.67	1.26	−.37	3.74	.58	16.87	.01
76b	71.91	.89		4.32		16.88	
77a	74.19	.90	−.14	4.05	.72	16.26	−.74
77b	73.69	.76		4.77		15.52	
97a	73.58	1.17	−.33	3.63	1.36	17.25	−1.11
97b	72.80	.84		4.99		16.14	
98a	73.67	1.10	−.18	3.83	1.28	16.93	−.99
98b	72.65	.92		5.11		15.94	
99a	74.20	1.23	−.38	3.81	.51	16.16	−.06
99b	71.44	.85		4.32		16.10	
THIRD EXPERIMENT (FIRST PERIOD)							
100a	74.78	0.86	0.02	2.76	1.25	17.15	−1.40
100b	72.65	.88		4.01		15.75	
101a	77.68	.56	.17	2.63	1.06	14.41	−1.69
101b	76.64	.73		3.69		12.72	
102a	74.43	.82	.11	3.39	1.29	17.41	−1.49
102b	73.25	.93		4.68		15.92	
103a	76.38	.75	.26	3.21	1.25	15.51	−1.81
103b	75.83	1.01		4.46		13.70	
104a	75.72	.77	.28	2.78	1.07	16.25	−1.38
104b	74.48	1.05		3.85		14.87	
105a	75.54	.96	.17	3.27	.77	16.10	−1.24
105b	74.99	1.13		4.04		14.86	
THIRD EXPERIMENT (SECOND PERIOD)							
109a	70.69	0.76	−0.23	4.53	0.34	19.10	0.05
109b	70.31	.53		4.87		19.15	
112a	74.76	1.61	−.55	4.32	.47	14.82	.02
112b	74.26	1.06		4.79		14.84	
113a	74.17	.94	−.24	4.42	.26	15.87	−.18
113b	72.95	.70		4.68		15.69	
114a	75.55	1.54	−.41	4.23	.26	14.31	.13
114b	74.05	1.13		4.49		14.44	
115a	73.42	.74	−.19	3.93	.49	16.69	−.43
115b	73.55	.55		4.42		16.26	
116a	74.40	1.28	−.26	4.49	.26	15.43	−.10
116b	73.76	1.02		4.75		15.33	

In connection with the changes in reducing sugar the effect of cutting on the behavior of the potatoes must be considered. One of the most pronounced effects of wounding plant organs is a stimulation of respiration. The respiration of sweet potatoes is nearly doubled when they are split longitudinally, and the effect, though decreasing, extends over many days. By reason of this increased respiration split potatoes consume a much larger part of their reducing sugar than do whole potatoes. Nevertheless, in spite of this excessive respiration, there was, on the whole, during the first period a slight increase in reducing sugar, which is significant in comparison with the distinct loss during the second period. It appears clear, therefore, that more reducing sugar was formed during the first period than during the second; for during the first period the production of reducing sugar kept pace with its utilization, while during the second period the production was not sufficiently rapid to compensate for the quantity used.

Further evidence that more reducing sugar is formed in the potatoes during the first period than is indicated by the figures in the difference column is furnished by the whole potatoes stored with the first set of halves and split at the end of the first period. The percentage of reducing sugar in these "a" halves of the second period is much greater than in the "b" halves of the first period, with which they are comparable as to time of storage. Unfortunately, there is no such control for the behavior of the halves stored during the second period.

The potatoes used in the third experiment at 30° C. were allowed to remain in the ground for 15 days after the vines had been destroyed. They may therefore be considered to have been in "storage" in the ground during that period. The temperatures during that time, as given by observations of the United States Weather Bureau at Washington, D. C., were as follows:

Date.	Maximum.	Minimum.	Mean.	Date.	Maximum.	Minimum.	Mean.
	°C.	°C.	°C.		°C.	°C.	°C.
Oct. 22	13.3	1.6	7.8	Oct. 30	12.8	5.6	8.9
23	17.8	1.6	10.0	31	8.9	1.6	5.6
24	18.9	13.3	16.1	Nov. 1	11.1	0	5.6
25	19.4	13.3	16.7	2	12.8	.6	6.7
26	17.8	10.6	14.4	3	16.7	−1.1	7.8
27	20.6	6.1	13.3	4	17.2	7.2	12.2
28	22.8	10.6	16.7	5	14.4	1.1	7.8
29	17.8	6.1	12.2	6	15.6	−1.1	7.2

If the cutting of the vines has any effect on the carbohydrate transformations in the roots, the initial changes in these potatoes would have been inaugurated during the period after the vines had been cut and while the roots were still in the ground. However, the changes in these followed the same general course as those in the freshly dug potatoes.

There was a large loss of starch and a great accumulation of sugar during the first period, very little further loss of starch and accumulation of sugar during the second period, and a slight increase in reducing sugar during the first period, with a small loss during the second. But if the data of this experiment are compared with the corresponding data of the first and second experiments, it will be noted that the starch content of the sweet potatoes in the third experiment at the time they were dug is, on the whole, lower than that of the freshly dug potatoes in the first and the second experiments, and the cane sugar is higher, as though a part of the starch had already been converted at the time when the roots were dug. Furthermore, it will be noted that the loss of starch and the increment in cane sugar during the first period are a little less than in the corresponding periods of the first and second experiments. These facts show that as a result of the cutting of the vines the carbohydrate transformations had been initiated in these potatoes while they were still in the ground, but that the changes did not proceed as rapidly at the temperature of the soil as at 30°.

The results of the experiments at 30° C. may be summed up thus: In the freshly dug sweet potatoes whose vines were intact there was a large loss of starch and increase of cane sugar during the first period of 12 days, and very little further change in these substances during the second period. The changes in reducing sugar are obscured by the active respiration induced by high temperature and wounding, but, on the whole, the data show that there was a more extensive formation of reducing sugar during the first period than during the second. The potatoes which had been left in the ground for some time after the vines had been cut showed the same general phases of change, but their starch content was on the whole lower and their sugar content higher at the time of digging, and the rate of starch conversion during the first period was lower than in the potatoes dug while the vines were still intact. These conditions indicate that the carbohydrate transformations had proceeded to some extent in these potatoes after the vines had been cut and while the roots were still in the ground.

If the experiments at 5° C. (Table IV) are now examined, a marked contrast is found between these and the experiments at 30°. In the first two experiments with potatoes whose vines had remained active up to the time of digging, the loss of starch during the first period is much less than at 30°, but the loss continues at approximately the same rate during the second period. With respect to the behavior of the cane sugar the contrast between the potatoes at 30° and those at 5° is equally marked. At 5° there is only an insignificant increase in cane sugar during the first period, but a marked increase during the second. The reverse is true of the reducing sugar. There is a considerable accumulation during the first period and a marked reduction during the second.

TABLE IV.—*Changes in the composition of sweet potatoes at 5° C.*

FIRST EXPERIMENT (FIRST PERIOD)

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Difference.	Cane sugar.	Difference.	Starch.	Difference.
	Per cent.	*Per cent.*		*Per cent.*		*Per cent.*	
33a	74.22	0.91	1.33	1.73	0.45	18.53	−1.89
33b	72.94	2.24		2.18		16.64	
34a	72.21	1.23	1.07	2.14	.35	20.29	−1.82
34b	72.20	2.30		2.49		18.47	
35a	71.28	1.27	.80	2.27	.38	20.45	−1.05
35b	69.22	2.07		2.65		19.40	
36a	71.02	1.37	.90	1.98	.79	20.92	−1.37
36b	70.71	2.27		2.77		19.55	
37a	73.99	1.40	1.00	2.07	.40	17.65	−1.06
37b	72.82	2.40		2.47		16.59	
38a	74.52	1.01	.71	2.18	.56	17.42	−1.16
38b	72.35	1.72		2.74		16.26	

FIRST EXPERIMENT (SECOND PERIOD)

39a	72.76	1.93	−0.34	2.62	1.89	18.00	−1.52
39b	70.71	1.59		4.51		16.48	
40a	73.46	2.19	−.21	2.88	1.62	16.94	−1.42
40b	72.40	1.98		4.50		15.52	
41a	73.74	2.17	−.12	3.06	1.66	16.69	−1.65
41b	72.37	2.05		4.72		15.04	
42a	72.59	1.79	−.13	3.18	1.16	17.76	−.90
42b	70.86	1.66		4.34		16.86	
43a	74.52	2.18	−.32	2.65	1.89	15.82	−1.45
43b	73.77	1.86		4.54		14.37	
44a	73.35	1.79	−.18	3.19	1.95	17.23	−2.17
44b	72.24	1.61		5.14		15.06	

SECOND EXPERIMENT (FIRST PERIOD)

82a	70.99	0.53	2.21	2.03	−0.12	21.26	−2.04
82b	72.61	2.74		1.91		19.22	
83a	76.07	1.14	1.04	2.06	−.04	16.41	−1.63
83b	75.93	2.18		2.02		14.78	
84a	72.38	.78	1.02	2.25	.48	20.37	−1.75
84b	72.51	1.80		2.73		18.62	
85a	73.49	.71	1.08	2.08	.21	19.37	−1.23
85b	72.53	1.79		2.29		18.14	
86a	73.47	.82	1.06	2.52	.28	18.94	−1.25
86b	72.11	1.88		2.80		17.69	
87a	73.99	.86	1.39	1.61	.34	19.25	−1.67
87b	72.87	2.25		1.95		17.58	

TABLE IV.—*Changes in the composition of sweet potatoes at 5° C.*—Continued

SECOND EXPERIMENT (SECOND PERIOD)

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Difference.	Cane sugar.	Difference.	Starch.	Difference.
	Per cent.	*Per cent.*		*Per cent.*		*Per cent.*	
88a	71. 16	1. 90	−0. 51	3. 12	2. 33	19. 23	−1. 61
88b	69. 99	1. 39		5. 45		17. 62	
90a	72. 32	2. 06	− . 27	2. 82	1. 99	18. 04	−1. 42
90b	71. 08	1. 79		4. 81		16. 62	
91a	73. 50	2. 40	− . 15	2. 40	2. 46	17. 04	−2. 55
91b	74. 43	2. 25		4. 86		14. 49	
92a	74. 48	1. 67	. 25	2. 91	2. 30	15. 72	−2. 21
92b	75. 24	1. 92		5. 21		13. 51	
93a	70. 65	2. 04	− . 18	3. 40	1. 99	19. 48	−1. 90
93b	71. 43	1. 86		5. 39		17. 58	
94a	73. 26	2. 08	− . 20	3. 66	1. 93	16. 97	−1. 46
94b	73. 16	1. 88		5. 59		15. 51	

THIRD EXPERIMENT (FIRST PERIOD)

125a	75. 81	0. 74	0. 57	3. 04	1. 88	15. 77	−2. 38
125b	76. 31	1. 31		4. 92		13. 39	
126a	74. 55	. 98	. 42	3. 43	1. 44	16. 79	−1. 96
126b	74. 72	1. 40		4. 87		14. 83	
127a	74. 27	1. 19	. 25	3. 48	1. 72	16. 89	−2. 32
127b	74. 52	1. 44		5. 20		14. 57	
128a	74. 87	1. 05	. 57	3. 01	1. 20	16. 78	−1. 92
128b	74. 80	1. 62		4. 21		14. 86	
129a	76. 38	1. 16	. 18	3. 32	1. 18	14. 62	−1. 78
129b	76. 00	1. 34		4. 50		12. 84	
130a	72. 65	. 87	. 35	3. 62	1. 25	18. 69	−2. 23
130b	73. 69	1. 22		4. 87		16. 46	

THIRD EXPERIMENT (SECOND PERIOD)

131a	73. 95	1. 44	−0. 19	4. 67	2. 67	14. 67	−2. 43
131b	72. 90	1. 25		7. 34		12. 24	
133a	76. 15	1. 49	. 53	4. 36	1. 90	13. 10	−2. 59
133b	77. 19	2. 02		6. 26		10. 51	
134a	75. 28	1. 89	. 22	4. 26	2. 12	13. 94	−2. 69
134b	76. 32	2. 11		6. 38		11. 25	
137a	73. 85	1. 58	. 09	4. 60	1. 90	15. 71	−2. 54
137b	73. 63	1. 67		6. 50		13. 17	
138a	72. 71	1. 55	− . 11	4. 91	2. 49	16. 26	−2. 59
138b	73. 40	1. 44		7. 40		13. 67	
139a	75. 55	1. 15	− . 31	5. 61	1. 60	12. 96	−1. 30
139b	73. 28	. 84		7. 21		11. 66	

In the third experiment at 5°, which was carried out with potatoes that had been left in the ground for some time after the vines had been destroyed, the conversion of starch took place during both periods as in the other two experiments, but in contrast with these the accumulation of cane sugar took place not only in the second but also in the first period. At the same time there was a slight increase in reducing sugar during the first period and scarcely any further increase during the second. A

further fact should be noted—viz, that the starch content of these potatoes at the beginning of the first period is comparable in general with that of the potatoes at the beginning of the second period in the other experiments, while the final starch is much lower than in the other two groups. Similarly, the cane-sugar content at the beginning of the first period is comparable with that of the other groups at the beginning of the second period, but the final cane-sugar content is much higher than in either of those.

Here it is even more evident than in the corresponding experiment at 30° C. that the carbohydrate transformations were well under way at the time when the sweet potatoes were dug and that the data given in Table IV merely show the continuation of the processes which had already been started in the ground.

If the experiments at 5° are now summed up, it is found that whether the potatoes had been dug while the vines were still active or some time after the vines had been destroyed there was a fairly uniform loss of starch during both periods. In the first two experiments only inconsiderable quantities of cane sugar were formed during the first period, but during the second period there was a marked accumulation of cane sugar. In the third experiment the accumulation of cane sugar was marked during both periods. In contrast to the cane sugar, there was a considerable accumulation of reducing sugar during the first period in the first two experiments and a slight loss during the second period. In the third experiment there was little or no accumulation during either period.

The results of the experiments at 15.5° C. (Table V) do not present the same degree of uniformity as those at the other temperatures, but certain definite tendencies are evident. In the first experiment the loss of starch was large during the first period, but during the second the loss was not so great. Correspondingly, there was a considerable quantity of cane sugar formed during the first period and much less during the second. Very little change in the reducing sugar is evident during the first period, but during the second there is a distinct loss. It should be recalled here that the halves used in this experiment lost a large amount of water and that their behavior may have been influenced thereby, for from the work of Lundegårdh [1] it appears that the balance between oil and starch and sugar and starch in seedlings is shifted with changes in moisture content. The behavior of the roots in the second experiment is probably more nearly normal. Here the loss of starch is lower during the first period than at 30°, with no further loss during the second. The accumulation of cane sugar is not as great at first as at 30°, but is distinctly larger than during the second period. The increase in reducing sugar during the first period was comparable to that observed at 5°. During the second period there was a slight loss.

[1] Lundegårdh, Henrik. Einige Bedingungen der Bildung und Auflösung der Stärke. Ein Beitrag zu Theorie des Kohlehydratstoffwechsels. *In* Jahrb. Wiss. Bot., Bd. 53, Heft 3, p. 421–463. 1914.

TABLE V.—*Changes in composition of sweet potatoes at 15.5° C.*

FIRST EXPERIMENT (FIRST PERIOD)

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Difference.	Cane sugar.	Difference.	Starch.	Difference.
	Per cent.	*Per cent.*		*Per cent.*		*Per cent.*	
10a	75. 18	0. 90	−0. 24	2. 30	2. 75	17. 17	−3. 07
10b	63. 44	. 66		5. 05		14. 10	
11a	73. 17	1. 09	− . 06	1. 84	2. 57	19. 49	−2. 97
11b	67. 55	1. 03		4. 41		16. 52	
12a	72. 96	. 82	0	2. 88	3. 14	19. 08	−3. 42
12b	62. 87	. 82		6. 02		15. 66	
30a	72. 77	. 75	− . 07	2. 09	2. 69	19. 63	−3. 68
30b	62. 20	. 68		4. 78		15. 95	
31a	73. 26	. 94	− . 25	2. 01	2. 73	19. 25	−3. 51
31b	67. 32	. 69		4. 74		15. 74	
32a	74. 13	1. 02	. 04	2. 44	2. 04	17. 96	−2. 36
32b	65. 64	1. 06		4. 48		15. 60	

FIRST EXPERIMENT (SECOND PERIOD)

24a	70. 10	1. 52	−0. 63	4. 17	2. 52	18. 53	−2. 06
24b	66. 82	. 89		6. 69		16. 47	
26a	71. 85	1. 16	− . 58	5. 12	. 86	16. 51	−1. 29
26b	68. 08	. 58		5. 98		15. 22	
29a	71. 64	1. 48	− . 60	3. 57	1. 94	18. 26	−1. 06
29b	66. 18	. 88		5. 51		17. 20	
51a	70. 71	1. 30	− . 41	4. 46	2. 46	17. 99	−1. 85
51b	67. 13	. 89		6. 92		16. 14	
52a	69. 12	1. 36	− . 33	5. 02	1. 12	19. 52	−1. 16
52b	66. 61	1. 03		6. 14		18. 36	
53a	71. 51	1. 44	− . 68	4. 52	1. 91	17. 89	−1. 68
53b	67. 74	. 76		6. 43		16. 21	

SECOND EXPERIMENT (FIRST PERIOD)

55a	74. 13	0. 65	1. 16	2. 11	0. 91	18. 52	−1. 78
55b	73. 23	1. 81		3. 02		16. 74	
56a	73. 42	. 82	1. 08	2. 66	. 75	18. 56	−1. 48
56b	73. 18	1. 90		3. 41		17. 08	
57a	73. 14	. 85	. 85	2. 23	. 87	19. 19	−1. 47
57b	71. 95	1. 70		3. 10		17. 72	
58a	73. 88	. 61	1. 00	2. 42	1. 00	18. 50	−1. 89
58b	73. 66	1. 61		3. 42		16. 61	
59a	75. 10	. 83	. 68	2. 56	. 91	17. 23	−1. 46
59b	73. 66	1. 51		3. 47		15. 77	
60a	75. 61	. 89	. 72	2. 13	. 58	17. 15	−1. 18
60b	73. 63	1. 61		2. 71		15. 97	

TABLE V.—*Changes in composition of sweet potatoes at 15.5° C.*—Continued

SECOND EXPERIMENT (SECOND PERIOD)

No. of sweet potato.	Moisture.	Reducing sugar as glucose.	Difference.	Cane sugar.	Difference.	Starch.	Difference.
	Per cent.	*Per cent.*		*Per cent.*		*Per cent.*	
64a	73.29	1.05	0.03	3.30	0.36	17.07	0.10
64b	72.39	1.08		3.66		17.17	
65a	72.92	1.50	−.16	2.54	.69	17.91	−.34
65b	71.50	1.34		3.23		17.57	
66a	70.53	1.76	−.42	3.69	.57	19.24	.13
66b	68.75	1.34		4.26		19.37	
67a	73.34	1.39	−.10	3.31	.49	16.84	−.36
67b	72.49	1.29		3.80		16.48	
70a	71.72	1.39	−.06	2.91	.40	18.78	−.35
70b	70.85	1.33		3.31		18.43	
71a	73.30	1.55	−.21	3.30	.59	16.97	−.23
71b	71.72	1.34		3.89		16.74	

THIRD EXPERIMENT (FIRST PERIOD)

106a	75.20	0.77	0.68	2.81	−0.05	16.35	−0.22
106b	74.32	1.45		2.76		16.13	
107a	76.92	.72	.49	3.20	.15	14.95	−.66
107b	74.43	1.21		3.35		14.29	
108a	77.38	1.13	.60	2.59	.42	14.65	−.91
108b	75.58	1.73		3.01		13.74	
122a	75.60	.93	.55	2.92	.45	16.01	−1.18
122b	75.48	1.48		3.37		14.83	
123a	75.75	.48	.50	3.90	.12	15.00	−.72
123b	72.63	.98		4.02		14.28	
124a	74.54	.98	.55	3.00	.12	17.33	−1.07
124b	74.24	1.53		3.12		16.26	

THIRD EXPERIMENT (SECOND PERIOD)

118a	72.76	1.62	−0.01	2.95	0.25	18.26	−0.77
118b	72.95	1.61		3.20		17.49	
119a	74.93	1.61	−.20	3.36	.06	15.73	−.12
119b	74.48	1.41		3.42		15.61	
120a	75.16	1.74	−.13	3.56	−.13	15.21	.13
120b	74.11	1.61		3.43		15.34	
141a	75.21	2.00	−.17	3.86	−.08	15.08	0
141b	74.53	1.83		3.78		15.08	
142a	73.73	1.48	.33	3.54	.64	16.42	−1.33
142b	75.14	1.81		4.18		15.09	
143a	75.26	1.68	−.15	3.26	−.04	15.24	.02
143b	75.57	1.53		3.22		15.26	

In the sweet potatoes which had already undergone a period of "storage" in the ground there was on the whole very little further loss of starch and practically no further accumulation of cane sugar. The reducing sugar shows distinct increase during the first period and a loss during the second.

DISCUSSION OF DATA

If the results of these experiments are considered in a general way, it is found that the rate of starch conversion varies with the temperature. At 30° C. the process is rapid at first, but soon appears to approach a point where no further conversion takes place. At 15.5°, if the second experiment is regarded as typical, the rate of starch hydrolysis is less rapid, but at this temperature also the process seems to approach a state of completion. At 5° the process is distinctly retarded, but it continues without decrease during the period covered by the experiments.

The rate of accumulation of cane sugar also varies with the temperature. At 30° the greater part of the cane sugar is formed during the first 10 to 12 days after the roots have been severed from the vines, but the rate of accumulation diminishes rapidly. At 5° very little cane sugar is produced during the first 10 to 12 days, but subsequently the rate of accumulation is considerably increased, as if there were a lag at first in the formation of cane sugar at this temperature.

The behavior of the reducing sugar is obscured by its utilization in respiration. It is nevertheless evident from the data presented in this paper and in former papers that at 30° C. the production of reducing sugar is sufficiently rapid to provide all that is used in respiration and still permit a considerable accumulation which, under normal conditions, is not far behind that at 5°. At 15.5° (second experiment) and at 5° there is a marked accumulation of reducing sugar at first, but at these temperatures, as well as at 30°, there is very little further accumuation, or even a slight subsequent loss.

The apparent lag at first in the accumulation of cane sugar associated with the marked accumulation of reducing sugar at low temperatures may throw some light on the process of the formation of cane sugar from starch. In the experiments at 5° C. reducing sugar was obviously formed during the first period as a result of the conversion of starch. The disappearance of starch continued at the same rate during the second period. During this period there was, however, no further increase in reducing sugar, but a large increase in cane sugar. Since it is not likely that in the one instance reducing sugar resulted directly from the conversion of starch, and in the other, cane sugar, it may be assumed that the production of reducing sugar went on at a rate corresponding to the loss of starch during both periods and that the excess which was produced during the second period was utilized in the formation of cane sugar. In this connection it is worthy of note that the concentration of reducing sugar always remains comparatively low. Even at low temperatures, at which starch transformation goes on continuously and respiration is reduced to a minimum, the reducing sugar content does not rise above 2 to 2.5 per cent. It appears, therefore, that with the exception of the quantity used for respiration the reducing sugar is transformed into cane sugar as fast as it is formed from starch. Its rate of transformation

would, therefore, be correlated with that of the starch. From these considerations it appears that the hydrolysis of starch in the sweet potato results directly in the formation of reducing sugar, as has been observed in cotyledons and other living plant organs, and that the cane sugar is synthesized from the reducing sugar. Cane sugar is therefore the end product of this series of carbohydrate transformations.

It has sometimes appeared from the extensive accumulation of cane sugar in plant organs at low temperatures that this process went on more rapidly at low than at high temperatures. Such a conclusion would seem to be justified if later phases of the process were compared at different temperatures, as illustrated by the data relating to the second periods of the experiments at 30° and at 5°. These data show that during these periods the loss of starch and the gain in sugar was greater at 5° than at 30°. On the basis of the interpretation given above, however, it is clear that all these reactions conform in general to the Van't Hoff temperature rule regarding chemical reactions. Thus, the rate of conversion of starch is higher at 30° than at 5°, but the reaction obviously approaches an end point which is more rapidly approximated at 30° than at 5°; hence, the reaction slows down more rapidly at 30° than at 5°. It is evident also that the production of cane sugar is more rapid at higher temperatures, and that the reaction, which is prolonged at 5°, nears an end point more quickly at 30°. Hence, if these reactions at different temperatures are compared in their later phases, they will appear to be more rapid at the lower temperature. In the common Irish potato, as well as in some other living plant organs, the series of reactions resulting in the production of cane sugar from starch has been found to be reversible. It is not unlikely that in the sweet potato also the reaction is reversible and that thus the attainment of a final equilibrium between the starch, reducing sugar, and cane sugar is explained. The end point of the reaction or the point of equilibrium is greatly shifted with change of temperature, with the effect that at low temperatures the system permits a greater concentration of sugar than at higher temperatures.

On the basis of these considerations a rational interpretation can be given of the rapid initial carbohydrate transformations, which have been mentioned several times and which it was in part the object of this work to study more fully. The fact that there is a comparatively rapid transformation of starch to cane sugar in sweet potatoes during the first few days after they have been dug and a very much slower transformation subsequently is supported by the data of the experiments conducted at 30° and at 15.5°. At 5°, however, the disappearance of starch continues at about the same rate during both periods, while the rate of accumulation of cane sugar is low at first and higher afterwards. All these facts are explicable by the interpretation given above. We have to do here with processes whose rate depends on the temperature and which at

higher temperatures approach an end point very rapidly, so that we find at first a rapid transformation and after a few days almost a cessation of the processes. At 5° the rates of the reactions are greately reduced, but the processes continue over a much longer period of time, and the starch conversion and sugar accumulation are much more extensive. At this temperature the course of the reactions becomes clear. The conversion of starch results in the formation of reducing sugar. As the concentration of reducing sugar increases, the rate of formation of cane sugar rises, but at first there is a lag in the production of cane sugar.

There remains to be considered the influence of the vines on the carbohydrate transformations of the sweet potato. From work formerly reported it appears that the conversion of starch to sugar does not take place to any marked extent in the growing potato, and that the inauguration of this process is probably associated with the cessation of the flow of materials from the vines. The data of the third series of experiments confirm this suggestion and show that when the vines are destroyed, even if the roots are left untouched in the ground, the carbohydrate transformations begin. In the third series of experiments carried out with sweet potatoes which were left in the ground for some time after their vines had been cut, there is evidence which has been set forth in the description of the experiments that the carbohydrate transformations were well under way when the potatoes were dug. It is therefore safe to conclude that the activity of the vines inhibits the conversion of starch to sugar in the growing sweet potato.

CONCLUSIONS

From the data given in this paper it appears that in the carbohydrate transformations in stored sweet potatoes starch is first converted to reducing sugar and cane sugar is synthesized from the reducing sugar. The rates of starch hydrolysis and of sugar synthesis in a general way conform to the Van't Hoff temperature rule for rates of chemical reactions. At high temperatures the reactions are rapid at first, but soon become slower and approach an end point. At low temperatures the rates are slower and the end point is so shifted as to permit a greater concentration of sugar. The reactions are continuous.

In the growing sweet potato the concentration of sugar remains comparatively low. The extensive conversion of starch into sugar appears to be inhibited by the activity of the vines. When the vines are destroyed and the flow of materials to the roots is thus interrupted, the carbohydrate transformations characteristic of stored sweet potatoes are begun, even if the roots are left in the ground.

DIURESIS AND MILK FLOW

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INTRODUCTION

In studying the comparative efficiency of the nitrogen of alfalfa hay (*Medicago sativa*) and corn grain (*Zea mays*) for milk production, data were accumulated and published from this laboratory which suggested that alfalfa hay when fed in large amounts often acts as a diuretic and thus depresses the volume of milk flow.[1] While this relation was not found with all the experimental animals (cows), it was, nevertheless, deemed of sufficient importance to merit the study of the influence of specific diuretics on milk flow, as it was barely possible that the diuresis which was produced upon the feeding of alfalfa hay was not in itself responsible for the depression of mammary activity.

In view of the importance which hitherto unknown constituents of diets and rations have lately assumed, it is of the greatest interest to dissect the various factors normally operative in the animal body when feeding any of our ordinary rations. Dairy chemists have spent much time and effort in studying the various factors which influence the secretion of milk and its composition. It seemed not improbable that if any of the well-known diuretics were able to influence milk secretion the means to vary the proportion of individual constituents might also be at hand.

EXPERIMENTS WITH DIURETICS ON GOATS

Two goats in full milk flow were used as the experimental animals. They were individually confined in metabolism cages which made possible the separate quantitative collection of urine and feces. They were fed and milked twice a day, the milk of two consecutive milkings being composited for analysis and measurement of volume. Careful measure of the water consumed and urine voided was recorded. Control of the ration consumed was kept only to the extent that results obtained could not possibly be due to variation in food intake. Goat 1, weighing 95 pounds, was fed daily a ration consisting of 2 pounds of oats (*Avena sativa*), 0.5 pound of June-grass hay (*Poa pratensis*), 60 gm. of air-dried casein, 1 pound of fresh sugar beets (*Beta vulgaris*), and 2 gm. of common salt (sodium chlorid). This provided sufficient energy and a suffi-

[1] Hart, E. B., Humphrey, G. C., Willaman, J. J., and Lamb, A. R. The comparative efficiency for milk production of the nitrogen of alfalfa hay and the corn grain. Preliminary observations on the effect of diuresis on milk secretion. *In* Jour. Biol. Chem., v. 19, no. 1, p. 127–140. 1914.

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ciently narrow nutritive ratio to serve excellently for milk production. Goat 2, weighing 81 pounds, was fed from 1.5 to 2 pounds of oats, 0.5 to 0.75 pound of June-grass hay, and 1 gm. of common salt daily, though the latter was often refused. Great care was taken that any variations in salt intake were not of sufficient moment to influence the character of the results obtained. Data obtained during periods of low consumption or of unusual restlessness of the animal were discarded, as such conditions obviously disturb the milk secretion. Everything possible was done to contribute to the comfort of the experimental animal, in accordance with good dairy practice.

First, it was desired to ascertain if specific diuretics were able at all to influence the volume of milk secreted. At the same time in some instances determinations of the total solids and nitrogen in the milk were made. As it was suggested in the publication referred to that the salts of the alfalfa ration might have been responsible for the diuresis, sodium acetate was the diuretic selected for the first trials. It was given per os to goat 1, at first with her drinking water, but later, as larger amounts were given, as a drench immediately after each milking. During a 4-day period, when there were administered, respectively, 20, 20, 50, and 50 gm. of sodium acetate daily, no diuresis resulted and no change in the milk volume occurred. It was not until the dose was increased to 80 gm. that the milk flow was materially affected, but even here, as seen in Table I, the diuresis was not pronounced.

TABLE I.—*Effect of sodium acetate on milk flow of goat 1*

Date.	Water.	Urine.	Milk.	Solids.	Nitrogen in 5 c. c.	Remarks.
	C. c.	*C. c.*	*C. c.*	*Per cent.*	*Mgm.*	
Nov. 24.....	2,950	1,150	860	15.89	34.7	No additions to ration.
25.....	2,000	750	830	16.40	35.7	Do.
26.....	3,000	1,250	880	15.84	31.5	Do.
27[a].....	2,700	1,250	610	18.22	33.7	Collection from 80 gm. of sodium acetate.
28[b].....	2,000	1,400	660	17.89	31.5	Collection from 100 gm. of sodium acetate.
29[c].....	1,725	450	925	14.34	30.0	No additions to ration.
30[d].....	2,950	635	930	15.25	31.4	Do.
Dec. 1.....	1,670	760	985	15.39	34.0	Do.

[a] Small amount of the casein beet mixture not consumed.
[b] No casein or beets consumed.
[c] No casein or beets given; 12 ounces oats left unconsumed.
[d] No casein given.

An increase in percentage of the solids in milk with the decrease in volume is pronounced, while the nitrogen content is unaffected. (See p. 566.) While the indications from the data on the administration of sodium acetate are that the volume of milk flow is decreased with diuresis, yet with the administration of such large amounts of the salt as was found necessary, too severe disturbances of the appetite resulted

to make the data serve their purpose. Furthermore, the urine was so strongly alkaline in reaction that from all appearances of the vulva a marked irritation of the urinary tract had resulted. Obviously sodium acetate was not a good diuretic to use for the solution of the problem at hand. Later some success was obtained with the use of sodium citrate, which with goat 2 upon the administration of 40 gm. in two portions increased the urinary volume from 170 to 550 c. c. and decreased the flow of milk from a volume of 395 to 350 c. c. Its use was not continued.

It was suggested that with the now well-known diuretic properties of the methyl purins, theocin might be a suitable agent. It was administered per os to goat 1 in gelatin capsules in two doses daily during a 9-day period, during which the daily dose was gradually increased to 600 mgm. Inasmuch as the dose for man ordinarily is given at 200 to 400 mgm., it must have been large enough; yet at no time was a diuretic effect noticed. Whether this is due to the difficulty of absorption with the ruminant was not determined, but at any rate during rumination the bitter taste of the regurgitated theocin destroyed the appetite of the animal to such an extent that even if it should have been effective in larger doses its continued administration was out of the question.

Urea was used next and with good results when given in large doses, as shown in Table II.

TABLE II.—*Effect of urea on milk flow of goat 1*

Date.	Water.	Urine.	Milk.	Remarks.
	C. c.	*C. c.*	*C. c.*	
Dec. 19	2,000	685	790	No additions to ration.
20	2,000	625	770	Do.
21[a]	2,675	1,925	500	Collection from 50 gm. of urea.
22	2,700	600	850	No additions to ration.
23	2,000	700	930	Do.
24	3,000	2,060	660	Collection from 30 gm. of urea.
25	2,900	1,160	855	No additions to ration.
26	2,525	1,260	780	Do.
27	3,285	1,825	640	Do.
28	2,450	850	786	Do.
29	1,000	460	700	Do.
30	2,575	500	755	Do.
31	1,925	625	740	Do.

[a] Little casein consumed; its feeding was discontinued from here on.

Urea when given in diuretic doses decreases the volume of milk secreted from 18 to 35 per cent, as seen in Table II. The diuresis in each case is followed by a period of one day in which the daily consumption of water is higher than normal, which suggests that the decreased flow of milk is caused by the withdrawal of body fluids from the mammary gland in an attempt of the animal to free its system of the diuretic. Compensation evidently is not immediately effected by the imbibition of sufficient water, and the body secretions are made to suffer as the result.

An attempt was made to accentuate the effect of the diuretic on the milk flow by keeping the water intake at a level which under normal conditions would be entirely sufficient for the animal, but with the additional requirements during diuresis draw heavily upon the body fluids. Goat 1 was used as the experimental animal. See Table III.

TABLE III.—*Effect of urea with constant level of water intake on milk flow of goat 1*

Date.	Water.	Urine.	Milk.	Solids.	Fat.	Nitrogen in 5 c. c.	Remarks.
	C. c.	*C. c.*	*C. c.*	*Per cent.*	*Pr. ct.*	*Mgm.*	
Jan. 26..	2,000	715	780	15.06	5.5	33.9	No additions to ration.
27..	2,000	640	840	15.06	5.4	33.2	Do.
28..	2,000	815	695	16.19	6.7	33.0	Collection from 30 gm. of urea.
29..	2,000	550	860	15.70	6.7	29.6	Do.
30..	2,000	675	900	15.06	5.5	32.8	Do.
31[a]..	2,000	260	845	15.99	5.9	33.6	No additions to ration.
Feb. 1..	2,000	855	725	16.18	5.9	35.7	Do.
2..	2,000	350	820	15.08	5.7	35.1	Do.

[a] Animal very restless; beets not all consumed.

As seen in Table III, renal activity after the effects of the first day was not sufficient to draw noticeably on the mammary secretion for fluids. At no time when urea was given, even in the above experiment, did the animal show any abnormal desire for water; in fact, the water supply when replenished in the morning was usually left untouched for some time. Yet it is hardly to be questioned that the animal was in great need of water. On the morning of February 2, after the previous day's collection had been made, 25 gm. of urea were given in one dose to determine whether larger quantities of urea were necessary to produce the desired results. This amount of urea, while large, would not furnish any more urea for excretion through the kidneys than 70 gm. of protein, and no untoward effects were expected. Yet five minutes after the urea was given the animal lay down and soon passed into violent convulsions, which terminated fatally in 1 hour and 15 minutes. A morphine hypodermic was of no avail in preventing death. A post-mortem examination gave no clue to the cause of death. Apparently the maximum quantity of urea which could possibly be retained with safety in the circulation had accumulated during the previous period of urea administration. With the sudden flooding of the system with the additional 25 gm. of urea the safety limits were exceeded and death resulted. Immediately previous to the administration of the final dose of urea the animal was ruminating and apparently normal in all respects. The urea used was a Kahlbaum preparation and undoubtedly was free from such other toxic compounds as cyanid or cyanate, as no untoward results followed the subsequent use of urea from the same reagent bottle. It was barely

possible that the previous severe régime of sodium acetate and purin feeding may have injured the kidneys sufficiently to account for the results obtained.

In other trials it was repeatedly demonstrated that the administration of urea upon consecutive days would not continue to influence milk secretion even though diuresis obtained. This is brought out in Table IV.

TABLE IV.—*Effect of repeated urea administration on the milk flow of goat 1*

Date.	Water.	Urine.	Milk.	Solids.	Fat.	Nitrogen in 5 c. c.	Remarks.
	C. c.	*C. c.*	*C. c.*	*Per ct.*	*Per ct.*	*Mgm.*	
Jan. 15...	1,850	1,135	880	15.00	5.6	33.5	No additions to ration.
16...	2,500	975	840	14.85	5.0	33.5	Do.
17...	2,850	1,125	840	14.56	5.4	34.3	Do.
18...	3,000	1,685	710	16.55	6.5	35.1	Collection from 30 gm. of urea.
19...	3,550	2,100	850	15.72	6.4	32.3	Do.
20...	4,000	2,410	780	16.12	6.8	32.2	Do.
21...	3,000	1,625	845	15.85	6.15	31.6	Do.
22...	3,000	735	965	15.10	5.7	31.7	No additions to ration.
23...	4,100	345	850	15.07	5.4	33.5	Do.
24...	2,075	525	875	15.00	5.25	33.9	Do.

It is significant that the consumption of water upon repeated administrations of urea increases with the diuresis. Whatever factors may be responsible for the symptoms of increased thirst when urea is given, they do not become operative until the water supply of the body is drawn upon so heavily that milk secretion is reduced. The stimulation of the mechanism for maintaining the concentration of the body fluids normal is then sufficient to cause the animal to imbibe enough water for all its excretory and secretory processes.

In this connection it was of great interest to determine the effect of the administration of sodium chlorid upon milk secretion. Table V gives the data obtained with goat 2.

TABLE V.—*Effect of sodium chlorid on the milk flow of goat 2*

Date.	Water.	Urine.	Milk.	Solids.	Fat.	Nitrogen in 5 c. c.	Remarks.
	C. c.	*C. c.*	*C. c.*	*Per ct.*	*Per ct.*	*Mgm.*	
July 19...	1,500	190	410	16.13	6.8	30.4	No additions to ration.
20...	1,050	155	390	16.25	6.5	30.4	Do.
21...	2,800	355	420	15.58	6.2	30.3	Collection from 20 gm. of sodium chlorid.
22...	1,175	355	400	15.91	6.6	30.3	No additions to ration.
23...	1,475	160	375	15.44	6.7	29.2	Do.
24...	2,425	580	410	14.59	5.5	28.8	Collection from 20 gm. of sodium chlorid.
25...	1,050	330	415	14.45	5.7	27.9	No additions to ration.
26...	800	170	395	14.77	5.7	29.0	Do.

While diuresis resulted and more water was lost through the gut, as indicated by a softer consistency of the feces, the volume of milk secreted was not decreased. This is to be explained by the fact that simultaneously with the increased urine flow more than sufficient water was consumed to cover the loss. By stimulation of thirst the excessive concentration of the body fluids was prevented, and the milk flow was not decreased.

In just what manner the relations between milk flow and urinary secretion with alfalfa hay are brought about is not clear. Whatever agent may be responsible for the diuresis, its action evidently is different from that of urea or sodium chlorid as observed in these studies with the goat.

INFLUENCE OF DIURESIS UPON THE COMPOSITION OF MILK

It will be noticed in Tables I and VI that with decrease of milk volume as caused by diuresis the percentage of total solids is increased. This increase is usually completely accounted for by the increase in fat content. The nitrogen content is not changed.

TABLE VI.—*Effect of diuresis on milk solids of goat 2*

PERIOD 1

Date.	Water.	Urine.	Milk.	Solids.	Fat.	Nitrogen per 5 c. c.	Remarks.
	C. c.	*C. c.*	*C. c.*	*Per ct.*	*Per ct.*	*Mgm.*	
May 21...	1,900	40	740	16.36	6.2	33.0	No additions to ration.
22...	1,800	140	705	16.38	6.4	32.7	Do.
23...	850	350	550	18.67	8.3	35.0	Collection from 20 gm. of urea.
24...	1,700	560	675	16.09	7.9	33.0	No additions to ration.
25...	1,570	100	640	16.89	6.9	33.9	Do.
26...	1,340	80	690	16.11	6.2	33.0	Do.
27...	1,490	350	600	16.83	6.9	33.0	Collection from 20 gm. of urea.
28...	1,300	110	650	16.45	6.8	30.9	No additions to ration.

PERIOD 2

June 1...	1,580	115	635	15.11	5.2	31.9	No additions to ration.
2...	1,830	140	620	15.30	5.4	30.3	Do.
3...	1,275	90	600	15.34	5.8	30.5	Do.
4...	1,800	380	540	15.91	6.3	30.4	Collection from 20 gm. of urea.
5...	1,125	145	600	15.58	5.9	29.5	No additions to ration.
6...	1,790	50	600	15.28	5.4	29.4	Do.
7...	1,850	365	550	15.86	6.4	29.6	Collection from 20 to 25 gm. of urea.
8...	1,940	220	640	15.31	6.0	27.5	No additions to ration.
9...	1,530	130	645	15.43	6.0	29.2	Do.
10...	1,450	130	655	15.05	5.8	29.8	Do.
11...	1,730	195	620	14.11	5.2	28.8	Do.

The constancy of the nitrogen content of the milk made it impossible that any of the administered urea found its way into the milk, which hypothesis was borne out by direct determination of urea in the milk.

One hundred c. c. of milk were measured off into a 250 c. c. volumetric flask, diluted with 100 c. c. of water, and the proteins removed at boiling temperature by the cautious addition of a 10 per cent solution of acetic acid. Generally about 1 c. c. was required. After cooling, the contents were made up to volume, set aside for 10 minutes, and then filtered through a dry folded filter. One hundred c. c. of the filtrate were pipetted off into an aeration bottle made slightly alkaline to phenolphthalein with a 10 per cent solution of sodium hydroxid and then acidified by the addition, drop by drop, of a 10 per cent solution of monobasic potassium phosphate (KH_2PO_4). After incubation for two hours at 41° C. with 2 c. c. of a 10 per cent solution of urease in the presence of toluol, the ammonia was aspirated into *N/28* hydrochloric acid. Fusel oil was used to prevent foaming. The air current was broken up into fine bubbles in the acid by firmly inserting a small plug of glass wool into the end of the tube dipping into the acid. Later, it was found feasible to make the urea determination without the previous removal of the milk proteins, as the fusel oil was sufficiently active in preventing foaming. A small amount of ammonia was found to be present in milk, but as this is practically negligible, the results are expressed as total ammonia in terms of milligrams of nitrogen per 100 c. c. of milk. (See Table VIII.)

TABLE VIII.—*Effect of the administration of urea to goat 2 on the urea content of milk*

Date.	Urea given.	Nitrogen as NH_3 and urea per 100 c. c. of milk.	Urine.	Milk.	Date.	Urea given.	Nitrogen as NH_3 and urea per 100 c. c. of milk.	Urine.	Milk.
	Gm.	*Mgm.*	*C. c.*	*C. c.*		*Gm.*	*Mgm.*	*C. c.*	*C. c.*
July 10...	0	13. 2	190	500	July 16...	20	11. 3	580	445
11...	0	10. 5	210	510	17...	20	7. 5	360	420
12...	0	13. 0	80	480	18...	20	10. 2	390	415
13...	0	9. 0	315	435	19...	0	7. 7	190	410
14...	0	9. 1	200	480	20...	0	11. 4	155	390
15...	20	11. 1	345	375					

The independence of the urea excreted and the urea put out in the mammary secretion strongly suggests that the urea in milk in large part is the result of mammary activity and not the result of a mere diffusion from the circulation.

CONCLUSIONS

(1) Urea administered in a diuretic dose is able to decrease temporarily the flow of milk. Upon repeated administration the increased intake of water which follows the impoverishment of the tissues with respect to

water content balances the draft for water imposed by the diuretic, and the milk secretion comes back to normal.

(2) Sodium chlorid with its diuretic action as well as its laxative effect is unable to depress milk secretion under normal conditions, as it simultaneously calls forth an excessive thirst, which increases the water intake.

(3) With the decreased flow of milk caused by a diuretic the percentage of solids is increased. Fat here is the principal variable.

(4) The mammary gland shows no tendency to absorb and subsequently put out in its secretion additional urea absorbed by the circulation.

(5) It is difficult to interpret the results sometimes obtained with alfalfa hay as due to diuresis alone if urea diuresis can be taken as a type.

PETROGRAPHY OF SOME NORTH CAROLINA SOILS AND ITS RELATION TO THEIR FERTILIZER REQUIREMENTS

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INTRODUCTION

In connection with the detail study of the soils of North Carolina, the writer has had occasion to make many mineralogical analyses of the existing soil types as defined by the United States Bureau of Soils. These examinations have included all types of any prominence thus far encountered in the survey and give some rather interesting data as to the formation and character of these soils which may be of more than local interest.

The available data showing the mineral composition of soils are meager. The scope of those found is so broad that definite conclusions can hardly be drawn as to the relationships which exist between the mineral component and the character of soils. The behavior of the various soil-forming minerals toward the forces of weathering will have to be known before the soil investigator will be able to solve many of the complex problems confronting him.

The methods used in these analyses are essentially those compiled by McCaughey and Frye.[1] Unfortunately, one serious criticism may be made regarding these methods—i. e., the defiance of members of the clay group against identification. It is quite possible that this group plays the most important rôle in the various soil phenomena of all the separates which compose the soil. Yet it would seem that since the clay owes its origin to the coarser particles, some definite knowledge of the composition of the latter would be imperative.

SOILS OF NORTH CAROLINA

The soils of North Carolina are quite heterogenous and furnish well-defined examples for a discussion of the petrography of soils. The State is divided into three provinces, determined largely by the physiographic provinces used in any study of physical geography. There are the old Appalachian, locally known as the Mountain section, Piedmont Plateau, and Atlantic Coastal Plain. As will be shown later, wide variations in the mineralogical composition of the soils of these provinces are encountered.

Practically all of the soils of the mountains are of residual origin and are derived from igneous and metamorphic rocks, mainly gneiss, schists,

[1] McCaughey, W. J., and Fry, W. H. The microscopic determination of soil-forming minerals. U. S. Dept. Agr. Bur. Soils Bul. 91, 100 p., 12 fig., 12 tab. 1913. Bibliography, p. 99–100.

and granites. The sandy loams, sands, and most of the loams are products of the gneiss and granites; the heavier loams, clay loams, and clays have been derived, for the most part, from schists.

With few exceptions, the soils of the Piedmont Plateau are residual. The rocks of this section are varied and complex, being composed of (1) such igneous material as diorite, diabase, gabbro, and granites; (2) such metamorphosed igneous material as gneiss, schists, and slate, and (3) such young sedimentary rocks as Triassic sandstone and shale.

None of the soils of the Atlantic Coastal Plain are residual. They all belong to the broad division known as "transported" and are composed of unconsolidated material laid down from the provinces of higher topography. Because of the abrasive and leaching forces which have entered into their formation, the least resistant minerals have been removed, quartz composing mainly the entire soil mass.

In the mineralogical composition of the soils series here reported, the average analyses of five samples of each series were taken. These samples were selected from widely separated areas in order that the series might be as nearly representative as possible. It was recognized at the outset that it would have been better to show the composition of the various types of a series, but space would not permit such procedure. However, it may be said as a general rule that there are no appreciable differences in the occurrence of the minerals in the various types of a series. There are wide variations in the preponderance of different minerals in the types, but usually each series carries the same minerals in all of its types.

To obtain these results, a separation by mechanical analyses of the sand, silt, and clay of each sample was necessary, and the mineral composition of the sand and coarse silt was determined. The clay particles were discarded as being too small for identification. The results are given in Table I, and include the estimation of all the minerals except quartz—the more abundant or characteristic minerals and the less abundant or secondary in quantity present.

A careful study of Table I will show some rather interesting data concerning the mineral component of the sand and silt particles of these soils. One of the most striking points is the wide difference in mineral complexity between soils of the Appalachian Mountains and those of the Piedmont Plateau and the Atlantic Coastal Plain. The soils of the Porters series are the predominating soils of the former province. The Toxaway soils, which are found in the valleys, are of alluvial origin modified by colluvial wash. In these soils there is a more decided occurrence of the original minerals of the parent rock than is found elsewhere.

TABLE I.—*Mineralogical composition of soils of North Carolina*

APPALACHIAN MOUNTAINS

Series.	Depth.	Percentage of minerals not quartz in—		Abundant minerals not quartz in—		Less abundant minerals in—		Remarks.
		Sand.	Silt.	Sand.	Silt.	Sand.	Silt.	
Porters (surface soil).	*Inches.* 0 to 8	52	60	Muscovite, biotite, epidote, orthoclase.	Biotite, muscovite.	Epidote, microcline, hornblende, magnetite, chlorite, tourmaline, rutile, zircon, sillimanite, serpentine, pyroxene, plagioclase, apatite.	Orthoclase, chlorite, microcline, epidote, sillimanite, rutile, zircon, hornblende, magnetite.	Soil characterized by high content of minerals not quartz, of which biotite and muscovite compose about 20 per cent.
Porters (subsoil)...	8 to 30	57	66	Biotite, muscovite, orthoclase, epidote.	.....do.....	Microcline, hornblende, magnetite, tourmaline, rutile, zircon, serpentine, pyroxene, plagioclase, apatite.	Hornblende, magnetite, chlorite, rutile, zircon, plagioclase, apatite.	As in the soil, the mica content is very high. Biotite is principally fresh; this also applies to orthoclase. Quartz is mainly primary.
Toxaway (surface soil).	0 to 11	50	57	Biotite, orthoclase, epidote, microcline, muscovite.	.....do.....	Hornblende, magnetite, chlorite, sillimanite, rutile, zircon, plagioclase, pyroxene, apatite.	Chlorite, magnetite, rutile, zircon, sillimanite, microcline, epidote, tourmaline.	Very high content of potash-bearing minerals. Biotite and orthoclase compose over 30 per cent. Both occur as fresh and altered fragments. Quartz grains somewhat rounded.
Toxaway (subsoil).	11 to 30	44	49	Biotite, orthoclase, epidote.	Biotite (altered and fresh), muscovite.	Hornblende, chlorite, magnetite, sillimanite, rutile, zircon, plagioclase.	Chlorite, magnetite, zircon, sillimanite, microcline, epidote, tourmaline.	High content of micas. Biotite at times shows deep-seated chemical alteration. Some secondary quartz present.

TABLE I.— *Mineralogical composition of soils of North Carolina*—Continued

PIEDMONT PLATEAU

Series.	Depth.	Percentage of minerals not quartz in—		Abundant minerals not quartz in—		Less abundant minerals in—		Remarks.
		Sand.	Silt.	Sand.	Silt.	Sand.	Silt.	
Cecil (surface soil)..	*Inches.* 0 to 8	30	34	Orthoclase, muscovite, biotite (altered and fresh), epidote, microcline.	Muscovite, biotite, orthoclase, epidote, microcline.	Hornblende, magnetite, rutile, zircon, chlorite, sillimanite, serpentine, garnet, plagioclase, apatite.	Hornblende, chlorite, sillimanite, rutile, zircon, magnetite, garnet.	Rather high content of minerals not quartz. Alteration has taken place among some of the minerals. Plagioclase and apatite found only as traces. Much secondary quartz.
Cecil (subsoil).....	8 to 36	28	33	Orthoclase, muscovite, biotite, epidote.	Muscovite, orthoclase, microcline, epidote.	Hornblende, chlorite, magnetite, zircon, rutile, sillimanite, garnet, serpentine, microcline, tourmaline, plagioclase, apatite.	Hornblende, chlorite, sillimanite, rutile, zircon, magnetite, plagioclase, apatite included in quartz.	Potash-bearing minerals most abundant. Minerals are for the most part altered. Much quartz-carrying infiltrated iron oxid.
Iredell (surface soil).	0 to 7	80	Very high.	Hornblende, epidote, augite, biotite.	Hornblende, epidote, biotite.	Muscovite, chlorite, magnetite, plagioclase, orthoclase, microcline, apatite (free and included in epidote).	Muscovite, chlorite, magnetite, plagioclase, orthoclase, microcline.	Quartz is a subordinate mineral in this series, it being less than 5 per cent in the silt. Potash feldspars occur as mere traces.
Iredell (subsoil)....	7 to 30	84	Very high.	Hornblende, epidote, augite, biotite.	Biotite, hornblende, epidote.	Muscovite, chlorite, magnetite, plagioclase, orthoclase, microcline, apatite (free and included in other minerals).	Chlorite, muscovite, magnetite, plagioclase.	Quartz is even less than in surface soil. Biotite has been altered to a lesser degree than found in the surface. Quartz is mainly primary.
Granville (surface soil).	0 to 10	35	40	Microcline, orthoclase.	Microcline, orthoclase.	Epidote, hornblende, magnetite, zircon, rutile, tourmaline, biotite, plagioclase, sillimanite.	Hornblende, epidote, biotite, magnetite.	Potash feldspars compose the greater part of minerals not quartz. Biotite shows deep-seated chemical alteration.
Granville (subsoil).	10 to 28	30	38	.....do.....	Microline, ortnoclase, muscovite.	Hornblende, epidote, magnetite, rutile, zircon, tourmaline, sillimanite, plagioclase.	Hornblende, epidote, magnetite, rutile, zircon.	Potash feldspars as high as 22 per cent of minerals not quartz. Generally more in the silt than found in the surface. Some secondary quartz.

Georgeville (surface soil).	0 to 6	12	16	Orthoclase.....	Orthoclase, muscovite.	Magnetite, sillimanite, epidote, hornblende, chlorite, rutile, zircon, biotite, tourmaline, magnetite, microcline.	Epidote, sillimanite, tourmaline, chlorite, rutile, zircon, biotite.	Much quartz-carrying coatings of iron oxid. Minerals are of a refractory nature. Biotite and orthoclase are badly altered.
Georgeville (subsoil).	6 to 26	14	16	.....do.....	Orthoclase, microcline, muscovite.	Epidote, sillimanite, hornblende, rutile, zircon, microcline, magnetite, tourmaline.	Epidote, tourmaline, sillimanite, chlorite, biotite, rutile, zircon.	Very much the same mineralogical composition as found in the surface soil.
ATLANTIC COASTAL PLAIN								
Norfolk (surface soil).	0 to 7	2 to 4	6 to 9	None.....	None.....	Orthoclase (residues), microcline.	Epidote, tourmaline, zircon, rutile, magnetite, sillimanite, hornblende, muscovite, biotite, garnet.	Soil characterized by low content of minerals not quartz. Those existing are of a decidedly refractory nature.
Norfolk (subsoil)...	7 to 28	5	9	.....do.....	.....do...	Orthoclase residues....	Epidote, tourmaline, zircon, rutile, magnetite, sillimanite, microcline, muscovite, chlorite, garnet, biotite.	Little difference between soil and subsoil in mineralogical complexity.
Portsmouth (surface soil).	0 to 6	1 to 3	4	.....do.....	.....do.....	Microcline, tourmaline, sponge spicules, zircon, rutile, hornblende, magnetite, muscovite, chlorite, garnet.	Sponge spicules, zircon, rutile, magnetite, hornblende, muscovite.	Only the highly refractory minerals and sponge residues present.
Portsmouth (subsoil).	6 to 26	2	5	.....do.....	.....do.....	Sponge spicules, microcline, orthoclase (badly weathered), muscovite, chlorite, magnetite, hornblende, zircon, epidote, tourmaline, garnet.	Weathered orthoclase, epidote, hornblende, rutile, zircon, muscovite, magnetite, sponge spicules.	Very much the same condition as found in the surface soil.
Orangeburg (surface soil).	0 to 8	6	7	.....do.....	Microcline.....	Orthoclase, microcline, epidote, hornblende, magnetite, zircon, rutile, tourmaline, chlorite, muscovite, garnet.	Orthoclase, epidote, hornblende, rutile, zircon, muscovite, garnet.	Orthoclase is badly weathered and hornblende shows signs of passing over into epidote. Much secondary quartz here.
Orangeburg (subsoil).	8 to 36	6	9	.....do.....	Orthoclase (residues), microcline.	Orthoclase, epidote, microcline, hornblende, magnetite, zircon, rutile, chlorite, tourmaline, garnet, muscovite.	Hornblende, epidote, magnetite, rutile, zircon, muscovite.	Soil characterized by much-weathered orthoclase. Very similar to the Norfolk series.

An average of five samples of soil of the Porters series, including types of different texture, shows that 52 per cent of the minerals in the very fine sand separates comprises other minerals than quartz. The potash-bearing minerals are decidedly the predominating ones. Biotite and muscovite mica have been found among the predominating minerals in all five samples, having an average of 20 per cent of all the minerals except quartz. Orthoclase is very abundant in the soils of this province; it, too, has been found among the abundant minerals in all five samples. Microcline is often encountered, especially among the sand particles; however, it is not found as abundantly as orthoclase. A study of the optical properties of biotite and orthoclase often shows them to be undergoing well-marked chemical alteration, the former being metamorphosed to chlorite and epidote and the latter wearing down, leaving a somewhat skeleton-shaped residue. Plagioclase[1] feldspars are encountered often in the soils of this locality; in many instances they are found as well-preserved fragments, which show clean faces and sharp edges, as though little decomposition had taken place.

Another point that may be worthy of note is the accumulation of micas in the silt separates. Not only is this true for the soils of the Appalachian Mountains, but it is most frequently the case with other soils of the United States. If these minerals are found in a soil to any appreciable extent, they usually occur in the largest quantities among the finer particles. This is readily accounted for from their cleavage and other physical properties, which cause them to be quite susceptible to the forces of weathering. As these minerals are carriers of the element potassium, practical significance may be attached to this fact. As they occur among the finer particles, more surface is exposed to the forces which make the soil solution, thereby causing more of this element to be of service to plant life than when found among particles of coarser texture.

Pyroxene and serpentine are found in more abundance in the Mountain soils than is usually the case with those of the Piedmont and Coastal Plain provinces.

Apatite, the mineral carrying the element phosphorus, is somewhat more common in these soils. It is found both as prismatic apatite and as tiny needles inclosed in other minerals. Fry [2] has called attention to the persistence of included apatite in soils, which may have some bearing on the availability of this element when so found.

The mineral epidote is often found among the predominating minerals of the soils in all parts of the State. Its persistence is readily explained, as it is a product of the metamorphism of the lesser resistant minerals, biotite and hornblende.

[1] The writer has not attempted to differentiate between the members of the plagioclase group.

[2] Fry, W. H. The condition of phosphoric acid insoluble in hydrochloric acid. *In* Jour. Indus. and Engin. Chem., v. 5, no. 8, p. 664-665. 1913.

Tourmaline, sillimanite, rutile, and zircon persist in many soil series; in fact, in very few in this State are they entirely absent. They are extremely resistant in character, which is undoubtedly the cause of their persistence.

The soils of the Cecil series are by far the most predominating of the Piedmont Plateau. Though formed from the same general character of rocks, they differ decidedly in mineral complexity. The quantity of minerals other than quartz in the Porters series is nearly double that of the Cecil series. However, minerals of nearly the same kind are encountered in both. As a general rule, greater decomposition has taken place among the minerals of the Piedmont soils; especially is this true of the silt particles. In many of the clay types of the Cecil soils biotite mica is found in only minute quantities, which would tend to show that it is passing out of existence in these older soils. Plagioclase feldspars and apatite are found only in very minute quantities in the soils of this series. Even the quartz particles appear to have undergone much greater wearing than in the mountains.

This is in accord with the work of Coffey [1] in showing the effect of topography upon the composition of soils. In the mountains the forces of erosion have not allowed the soil mantle to become as well defined as it is in the Piedmont Plateau; consequently, there is greater preponderance of the minerals found in the parent rocks when the superficial covering is removed. This fact is better illustrated in the accompanying reproductions of photomicrographs of representative soils of the two provinces (Pl. LII). Quartz and some of the other minerals are eliminated in these cuts, but the relative number of minerals other than quartz in the two samples is easily discernible.

The Iredell soils are formed from the basic eruptives, mica diorite, gabbro-diorite, and meta-gabbro. Quartz is a subordinate mineral, for in the sand portions of five samples whose averages were taken 80 per cent of other minerals than quartz is found. Among the silt particles quartz amounts to only about 5 per cent of the total minerals. Epidote, hornblende, and augite compose the greater part of the particles of coarser texture, while biotite and pyroxene are found more abundantly in the silt. Very little decomposition had taken place among any of the minerals found in this series; even the plagioclase feldspars, which occur in rather large quantities, do not show signs of serious chemical decomposition. An interesting point is the scarcity of the potash feldspars, orthoclase and microcline. Apatite is found in much larger proportions than in any other soil series in North Carolina, which is in accord with the total chemical analysis. As an average of five samples of the Iredell loam, the phosphoric-acid content is found to be 6,251 pounds per acre

[1] Coffey, G. N. A study of the soils of the United States. U. S. Dept. Agr. Bur. Soils Bul. 85, 114 p., map. 1912.

for the first 6⅔ inches, which is considerably higher than the average for the soils of the State. Field experiments which have been conducted on this series for the past five years indicate that phosphorus is in no way the limiting element in crop production.

The Granville soils, which are found in limited areas in the Piedmont Plateau, are formed from sandstone and shale. These soils are unusually high carriers of potassium, which is supplied mainly as microcline and orthoclase. While some biotite and muscovite are encountered, very little of the potassium must come from this source. It would be interesting to have field data on the requirements of the soils of this series for potassium, for comparison with those of the Mountain province, in which mica predominates.

The Georgeville soils represent those formed from Carolina slate, and the minerals other than quartz are mainly the potash feldspars and those of a highly refractory character. Many of the particles carry an infiltration of iron oxid, which makes identification quite difficult. Much of the orthoclase and biotite is badly altered, while other particles of these minerals are found in an unusually fresh condition, which indicates that an admixture of the material which enters into the formation of this soil has taken place.

The soils of the Atlantic Coastal Plain are characterized by their low content of other minerals than quartz. The Norfolk and Portsmouth series are by far the prevailing soils of this province, and, with few exceptions, no particular mineral other than quartz predominates. It might be said in passing that a few instances occur in which the other minerals than quartz will run higher, but this is unusual.

The average among the sand particles for the Norfolk series will not exceed 5 per cent of minerals other than quartz, of which none predominate. Among the particles the size of silt will be found orthoclase residues, microcline predominating. The less abundant minerals are composed mainly of a heterogeneous mixture of the more refractory minerals found in the provinces of higher topography. A point of interest is the scarcity of the micas in the series; they are encountered often, but the quantity found is usually so small that they can be of little value in maintaining the potash content of the soil solution. Apatite and the plagioclase feldspars are rarely found, as they have passed out of existence during the formation of this soil.

The Portsmouth soils are quite similar to the Norfolk, the only distinctive difference being in the amount of organic matter found in the former. On account of their location, which is usually in submerged or recently drained areas, an accumulation of vegetable matter is encountered. The average content of minerals other than quartz in this series is even lower than that of the Norfolk, being 3 per cent. The persistence of sponge spicules or Rhizopoda casts in this series is rather

interesting. These ham-shaped, isotropic particles are the remains of some form of life that flourished here during the submergence of this land.

In the Orangeburg series occurs a higher content of minerals other than quartz than is found in either the Norfolk or the Portsmouth series, but still the amount is small. The soils of the Orangeburg series resemble the Norfolk in many respects, and the same general minerals are encountered.

The low content of other minerals than quartz in the soils of the Atlantic Coastal Plain is in close agreement with the total chemical analyses of the three plant-food constituents—phosphoric acid, potash, and lime. Many chemical analyses of the soils of this province show the above-named elements of plant growth to be exceedingly low. Not only do there appear to be close relationships existing between the total chemical analyses and their mineralogical complexity here, but in the soils of the entire State. This would suggest that since the petrographic methods have reached so high a state of development they may be used with a fair degree of accuracy for estimating the amounts of the mineral plant-food constituents carried by a soil. On account of the ease of manipulation and the time saved in their use, they lend themselves readily for such purpose; especially is this true in scanning soils for the farmer. The information gained is usually not commensurate with the time and expense involved in making "bulk analyses" of soils for farmers. As a rule, it is not necessary that he know the exact number of pounds of plant food contained in his soil; an approximation will usually suffice. A very close estimate as to the quantity of the elements present may be easily secured with the microscopic methods; even more, the way these elements are held is revealed. If more data were at hand showing the availability of the various mineral elements of plant growth furnished by the different soil-forming minerals, more definite information could be obtained as to the fertilizer requirements of the land with the microscope than by "bulk analyses."

In a former publication [1] the writer submitted data from which there appeared to be some relationships existing with certain crops between the mineralogical and chemical composition of the soils of this State and their requirements for the inorganic elements found in the usual fertilizer mixture—namely, phosphoric acid, potash, and lime. Additional evidence will be submitted along this line, using the cotton plant as the indicator for measuring the relative densities of the soil solution.

In Table II will be found the average results of seven years' fertilizer treatments with cotton at the Iredell Substation, located upon typical Cecil clay loam.

[1] Plummer, J. K. Relation of the mineralogical and chemical composition to the fertilizer requirements of North Caroliua soils. N. C. Agr. Exp. Sta. Tech. Bul. 9, 29 p. 1914.

TABLE II.—*Average yield of cotton on fields A, B, and C, with seven years' fertilization at the Iredell Substation*

Treatment.	Average yield of seed cotton per acre.			Average increase per acre due to fertilizer.
	Field A (1903, 1904, 1906, and 1909).	Field B (1905 and 1907).	Field C (1908).	
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Nitrogen	210. 6	377. 5	505. 0	−11. 7
Phosphoric acid	655. 6	897. 5	860. 0	441. 8
Potash	301. 3	537. 5	435. 0	85. 4
Nitrogen and phosphoric acid	897. 5	727. 5	620. 0	520. 1
Nitrogen and potash	348. 8	406. 3	400. 0	96. 5
Phosphoric acid and potash	855. 0	959. 8	725. 0	608. 0
Nitrogen, phosphoric acid, and potash	923. 8	1, 002. 3	1, 070. 0	717. 7
Lime	97. 5	160. 0	430. 0	27. 0
Lime, nitrogen, phosphoric acid, and potash	728. 8	637. 5	945. 0	573. 5

A glance at Table II will show that phosphoric acid is the limiting or controlling element of plant growth for this soil. An average increase for the seven years' treatment of 441.8 pounds is obtained with phosphoric acid alone, while there was an increase of only 85.4 pounds with potash and no increase at all with nitrogen. Nitrogen added to phosphoric acid produced but a slight increase over the latter constituent alone, while potash added to phosphoric acid produced a somewhat better yield.

Table III shows an 8-year average with cotton at the Experiment Station Farm at Raleigh with typical Cecil sandy loam.

TABLE III.—*Average yield of cotton on fertilized fields A and B at the North Carolina Experiment Station Farm, Raleigh*

Treatment.	Average yield of seed cotton per acre.		Average increase per acre due to fertilizer.
	Field A (1902, 1903, 1904, 1906, and 1908).	Field B (1905, 1907, and 1909).	
	Pounds.	*Pounds.*	*Pounds.*
Nitrogen and phosphoric acid	1, 154. 5	768. 2	415. 1
Nitrogen and potash	994. 6	437. 7	169. 9
Phosphoric acid and potash	1, 126. 0	895. 3	464. 4
Nitrogen, phosphoric acid, and potash	1, 130. 8	925. 7	524. 6
Lime	619. 5	320. 1	31. 9
Nitrogen, phosphoric acid, potash, and lime	1, 007. 2	975. 3	572. 7

The 8-year average with cotton given in Table III again shows that phosphoric acid is the controlling element in these fertilizer tests. When potash and nitrogen are used in quantities, as in this experiment, only slight increases in yield are produced. The former constituent gave a slightly greater average than did the latter. The average "bulk analyses" of many samples of soil from these two fields, as well as from Norfolk fine sandy loam, will be found in Table IV.

TABLE IV.—*Average quantity of the total plant-food constituents per acre in various types of soil*

SURFACE SOIL TO DEPTH OF 6⅔ INCHES (2,000,000 POUNDS)

Soil type.	Nitrogen (N).	Phosphorus pentoxid (P_2O_5).	Potassium oxid (K_2O).	Calcium oxid (CaO).
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Cecil clay loam	1,141	1,155	7,213	4,656
Cecil sandy loam	769	503	2,994	5,542
Norfolk fine sandy loam	853	953	3,087	3,220

SUBSOIL TO DEPTH OF 28 INCHES (8,000,000 POUNDS)

Cecil clay loam	2,378	9,169	25,090	19,933
Cecil sandy loam	1,993	4,007	19,073	26,512
Norfolk fine sandy loam	1,360	1,573	11,453	8,880

A comparison of the yields of cotton on the two fields shows marked similarity in fertilizer requirements though the fields are over 100 miles apart. These soils belong to the same series, though of decidedly different texture, one being a rather heavy clay, the other a medium sandy loam. Unquestionably there are numerous other factors than the amount of plant food carried by the two soils which enter into their productiveness; nevertheless, some relationships exist between this question and their requirements for these fertilizer elements. As shown in Table IV, the phosphoric-acid content of both soils is low; until this element has been added in sufficient quantities there can be no increase yields. Although the nitrogen supply in the two soils is found in about the same proportion as the phosphoric acid, it is evidently changed into a more available form faster than the latter element.

The potash content of the Cecil clay loam is about double that of the Cecil sandy loam, both soils showing that potash is in no way the limiting element. Indeed, it is doubtful whether this element can be applied to the former at a profit. A glance at Table I, which gives the mineral composition of the Cecil series, shows that in the fine sand and silt separates the potash minerals predominate and that biotite mica is found among the abundant minerals in all five samples.

Lime has not given material gains with cotton in either test, owing undoubtedly to the physical condition of this land and the large amount of lime carried by the two soils. As a general rule, the minerals which carry lime in the Piedmont soils are more susceptible to chemical and physical decomposition than those found among the fields of the Atlantic Coastal Plain.

Table V gives the average yield of cotton on Norfolk fine sandy loam at the Edgecombe Substation with seven years' fertilization.

TABLE V.—*Average yield of cotton on fields A and B with seven years' fertilization at the Edgecombe Substation*

Treatment.	Average yield of seed cotton per acre.		Average increase per acre due to fertilizer.
	Field A (1903, 1904, 1906, and 1908.)	Field B (1905, 1907, and 1909.)	
	Pounds.	*Pounds.*	*Pounds.*
Control	1,030	429	.....
Nitrogen and potash	1,215	1,059	376
Phosphoric acid and potash	1,076	873	217
Nitrogen, phosphoric acid, and potash	1,193	1,022	348
Nitrogen and phosphoric acid	1,108	717	167
Lime	1,061	510	62
Lime, nitrogen, phosphoric acid, and potash	1,441	1,024	499

Table V gives the results of fertilizer tests which are in marked contrast to those obtained from the Cecil series of the Piedmont Plateau. Fertilizer mixtures carrying potash give the most marked yields; in fact, nitrogen and potash give greater returns than the three fertilizer constituents.

Lime in connection with the three fertilizer elements has produced decided gains. The physical condition of this soil is surely as good as that of the Cecil sandy loam at Raleigh, and the amount carried by the soil is quite sufficient to furnish this constituent as a plant food for a number of years to come. The petrographic examination of the Norfolk soils gives epidote as the only lime-bearing mineral of any consequence. It would seem therefore that lime carried in this form is of doubtful value in performing its functions in the soil.

The amount of potash here is even greater than that found in the sandy loam at Raleigh, yet potash seems to be the limiting element on this field. Weathered orthoclase and microcline furnish practically all the potash supply of this soil, while biotite and muscovite micas are much more abundant in the Cecil series.

Another interesting point brought out in these experiments is in regard to the phosphoric-acid content of the three fields. In the Edge-

combe field the content of phosphoric acid is somewhat less than that of the Cecil clay loam at the Iredell farm, yet in the latter soil phosphorus is the limiting element; but this is not the case in the former, owing doubtless to the way this constituent is held in the two soils. The supply of phosphorus must be stored in the organic form. There is practically no apatite in this Norfolk soil, while it is readily encountered in the residual soils of the Piedmont Plateau, occurring both free and included in quartz and other minerals.

CONCLUSIONS

The results of this and other work on the subject indicate that the following conclusions can be drawn, some of which are undoubtedly applicable to other than North Carolina conditions.

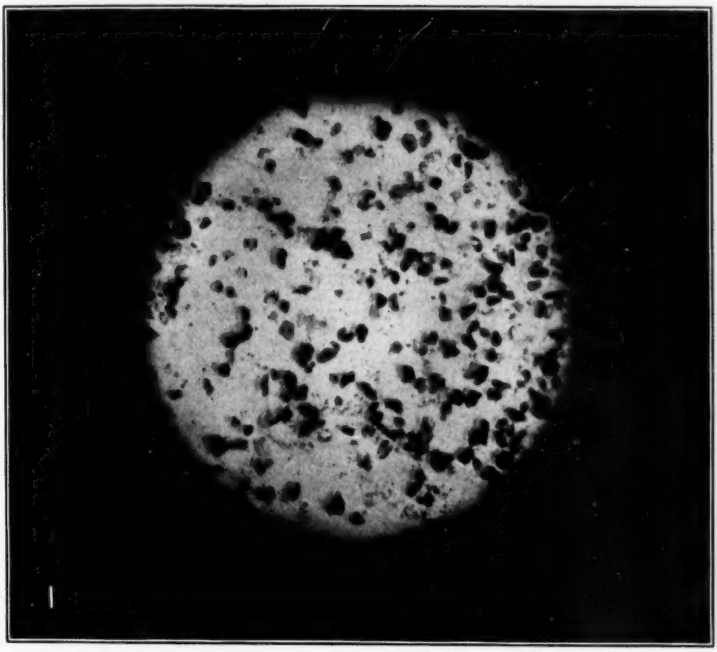
Wide variations in mineralogical composition are found between the soils of the Appalachian Mountains, Piedmont Plateau, and Atlantic Coastal Plain. There is unquestionably a greater supply of minerals which carry the inorganic plant-food constituents in the Mountain soils than are found in either the Piedmont Plateau or the Coastal Plain. Though many of the former soils are derived from the same rocks as those of the Piedmont province, the forces of erosion among those of the mountains cause them to contain minerals more nearly the same as the parent rocks than are found elsewhere.

Definite information is required on the behavior of the various soil-forming minerals to the forces of weathering before positive conclusions can be drawn on the availability of the plant food carried by the different minerals.

The field results with the cotton plant indicate that there are some relationships existing between the mineral component of the soil and the requirements of this plant for the three inorganic fertilizer constituents, phosphoric acid, potash, and lime.

PLATE LII

Fig. 1.—Photomicrograph of Porters soil of the Appalachian, No. 5 sand.
Fig. 2.—Photomicrograph of Cecil soil of the Piedmont Plateau, No. 5 sand.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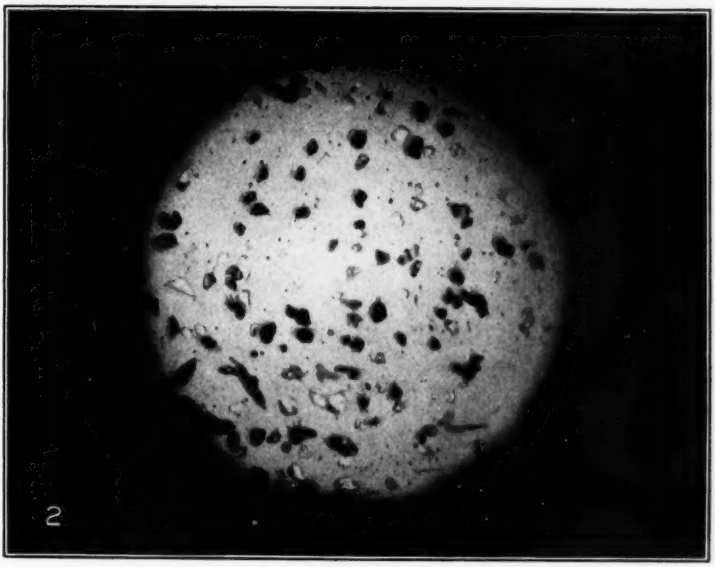
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